

Electrical Resistivity “Cross-over” Regime in $(V_{0.972}Cr_{0.028})_2O_3$

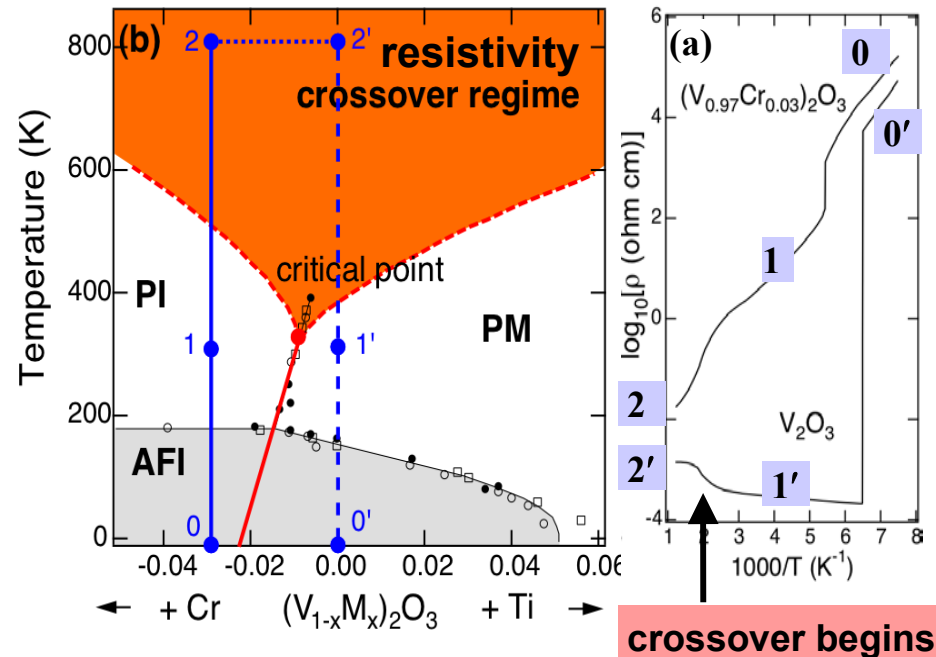
J.W. Allen, University of Michigan, DMR Award # 0302825

The electrical behavior of materials is one of their most useful and interesting properties. Metals are good conductors of electricity and insulators are not. Most materials are either one or the other.

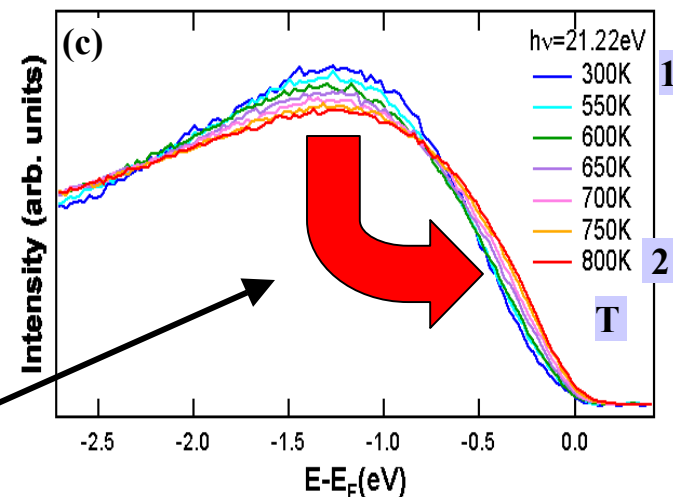
The alloy system $(V_{1-x}R_x)_2O_3$ ($R=Cr,Ti$) is famously strange because changing temperature T or composition (Ti or Cr) causes switching between an insulator (PI and AFI) or a metal (PM) (see regions of “phase diagram” in panel (b) at right).

A new theory called “dynamic mean field theory,” predicts a “cross-over” regime (red) which is neither metal nor insulator --but a “bad” version of each---fanning out from a “critical point.” Electrical resistivity (panel (a)) shows the crossover on two T - paths marked in blue.

Using a technique called photoelectron spectroscopy performed up to unusually high temperatures along the path $1 \rightarrow 2$ we have observed the change in the energy distribution of electrons that causes this strange “cross-over.”



Change in Distribution of electron energies with increasing temperature T along path $1 \rightarrow 2$ causes strange “cross-over”



The difference between metals and insulators is of great practical importance. For example electrical wiring in buildings uses a good metal to conduct the electricity, contained inside a good insulator to protect against short circuits and to maintain safety for people. Although much is understood about the science of the electrical properties of materials, there still remain mysteries. One mystery concerns materials that can switch abruptly from being metals to being insulators as their temperature T is changed. One of most famous is the material studied here, vanadium sesquioxide (V_2O_3) in which a small percentage x of the vanadium is replaced by either titanium or chromium, $((V_{1-x}R_x)_2O_3$ ($R=Ti$ or Cr)). Panel (b) above summarizes the ranges of x and T which are either metallic (PM region) or insulating (PI and AFI regions). (A slight complication is that this material's magnetic properties also vary---P means "paramagnetic" and AF means "antiferromagnetic" but that is not important for the story we are telling here.) Along the temperature path 0' to 1' the material changes abruptly from insulator to metal and along the temperature path 0 to 1 it is always an insulator, although its magnetic state changes abruptly. These abrupt changes show up in the temperature dependence of the electrical resistivity, as seen by the sharp jumps in the graphs of panel (a). The boundary between the PI and PM regions ends in a "critical point." A new theory predicts that the red region in panel (b), fanning out from this critical point, is a strange "cross-over" regime in which the material is neither a good metal nor a good insulator. Notice that the two graphs of panel (a) move quickly toward one another as the cross-over begins and the difference between the metal and insulator becomes blurred. As shown in the bottom panel we have measured the change in the quantum mechanical distribution of electron energies that brings about the cross-over behavior along the path 1 to 2 as the red region is entered. Our results can be used to test the details of the new theory, as published in *Physical Review Letters* **93**, 076404 (2004).

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International Collaboration:

This work** is an international scientific collaboration between researchers in four countries on three continents. It illustrates well how science builds bridges that can cross the boundaries of both culture and language

Photoemission experiments were performed at the University of Michigan with researchers from Pohang, Korea and Osaka, Japan using samples prepared at Purdue University.

The theoretical “dynamic mean field theory” calculations were performed by a researcher in Stuttgart, Germany

Education:

This grant provides partial support for two graduate students, Sung-Kwan Mo and Feng Wang. Both have passed their Ph.D. candidacy exams.

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